

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Henry AZIMA et al.
Title: ACOUSTIC DEVICE AND
METHOD FOR DRIVING IT
Appl. No.: 09/834,960
Filing Date: 04/16/2001
Examiner: Unassigned
Art Unit: Unassigned



CLAIM FOR CONVENTION PRIORITY

Commissioner for Patents
Washington, D.C. 20231

Sir:

The benefit of the filing date of the following prior foreign application filed in the following foreign country is hereby requested, and the right of priority provided in 35 U.S.C. § 119 is hereby claimed.

In support of this claim, filed herewith is a certified copy of said original foreign application:

- United Kingdom Patent Application No. 0009133.0 filed April 14, 2000.

Respectfully submitted,

Date AUG 07 2001

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A handwritten signature in black ink, appearing to read "Alan I. Cantor".

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The Patent Office
Concept House
Cardiff Road
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NP10 8QQ

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

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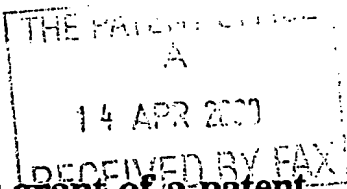
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Dated: 2 May 2001

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Patents Form 1/77

The
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Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form).

The Patent Office

Cardiff Road
Newport
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1. Your Reference

P.6146.GBA

2. Patent
(The Patent)

0009133.0

14 APR 2000

17APR00 E529485-1 002824
P01/7700 0.00-0009133.0

3. Full name, address and postcode of the or of each applicant (underline all surnames)

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Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

G.B.

7283476002

4. Title of the invention

Acoustic device and method for driving it

5. Name of your agent (if you have one)

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

MAGUIRE BOSS
5 Crown Street
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PE17 4EB

Patents ADP number (if you know it)

07188725001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (if you know it) the or each application number

Country

Priority application number
(if you know it)Date of filing
(day/month/year)

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application

Date of filing
(day/month/year)

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if:

Yes

- a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body:)
See note (d)

5 TITLE: ACOUSTIC DEVICE AND METHOD FOR DRIVING IT

10 DESCRIPTION

15 This application relates to an acoustic device and a method of driving it, particularly to a method of driving a resonant bending wave loudspeaker using digital pulses.

Resonant bending wave loudspeakers are becoming more and more widely available. Such speakers are described, 20 for example, in WO97/09842. In general, such speakers include a resonant bending wave plate and a transducer mounted on the plate to convert electrical signals into mechanical vibrations. The transducer excites the resonant bending wave modes in the plate, which then emit sound to 25 create an acoustic output.

Of course, most loudspeakers known to date are not resonant bending wave loudspeakers, but conventional pistononic loudspeakers having a magnet and voice coil



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arranged to drive a diaphragm. Piezo electric speakers are also known.

A development of such conventional loudspeakers is the digital loudspeaker described in the PCT patent application 5 WO96/31086. This document describes a digital loudspeaker having a large number of transducers which are driven by a so called "unary" code. In such a digital loudspeaker each of the many transducers is driven by a digital signal, i.e. a signal with the value binary 0 or binary 1. This patent 10 application describes a way of generating suitable digital signals. The individual digital signals are summed in the human ear, and to some extent in the 3D acoustic space, to produce a combined audio signal.

According to a first aspect of the invention, there is 15 provided a method of producing an acoustic output in a predetermined frequency range, comprising

providing a plate capable of excitation in a plurality of bending waves distributed over the predetermined frequency range, and an array of transducers coupled to the 20 plate spaced apart by less than the bending wavelength at the high frequency limit of the predetermined frequency range, and

driving the individual transducers with a plurality of digital pulses with time delays between pulses applied to 25 different transducers selected to excite at least one selected bending wave, so as to produce an acoustic output at the frequency or frequencies of the selected at least one bending wave.

By spacing the transducers close enough together the bending waves are correlated between neighbouring transducers.

The time delay between pulses applied to transducers 5 may be determined by the relative phase of the selected bending wave between the pair of transducers. Moreover, the number of transducers activated may be determined by the level of an analogue signal to be reproduced. In this manner, the digital pulse transducers sum to coherently 10 excite the plate modes, which in turn radiate acoustic energy.

The transducers may be arranged to excite travelling waves; when these travelling waves interact with the boundaries they may reflect and interfere to produce a 15 resonant mode at the frequency of the excited travelling wave.

The pulses may excite a travelling wave starting from a point source, to model a transducer at that point, by applying time delays determined by the phase differences of 20 such a wave. Alternatively, the pulses may excite a plane wave by applying the different time delays of such a wave to the pulses. Indeed, it should be possible to select the source and form of the excited wave.

The invention may reduce one of the problems of 25 conventional distributed mode panels, namely that an exciter may not efficiently excite those resonant modes for which the exciter is located at a node. In contrast, the invention may allow excitation of any mode, by



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appropriately selecting the excited wave.

In a device according to the first aspect integration of the digital signals occurs in the plate, not in the 3D acoustic space. The scheme outlined affords the possibility of performing an integration of the digital pulses in a two dimensional mechanical excitation, rather than in the 3D acoustic space. In this situation the problem of non-perfect summation in the 3D space is avoided. The integration in the plate is much more accurate due to the reduction in the degrees of freedom of motion from 3 to 2, and the access of the digital transducer to the complete space of integration. This is in contrast to the standard 3D integration, where the digital transducers only have access to a small part of the integration medium, resulting in distortions where their summation is imperfect.

This approach to the digital summation is inherently linked to a controlled excitation of the individual plate modes. It therefore affords a good level of control with regard to the bending wave distribution in the plate and its radiation characteristics. In this manner it is possible to control the directivity and diffusivity of the resulting radiation, within certain constraints determined by the material parameters of the plate.

Note that the panel constraints are not present in the prior art 3D acoustic integration model, which in principle is capable of producing a more flexible output. However, the number and density of transducers required for this to

be the case makes such an implementation prohibitively complex and expensive.

Since the transducer activation may be matched to the shape of the plate mode excited, the efficiency of 5 excitation may be very high.

The digital integration is no longer in the 3D acoustic space, and is therefore independent of the position of the listener. This indicates that the listener is not limited to be in the far field and near field applications such as 10 telephony are readily possible.

In a digital arrangement with a small number of exciters, there may occur the problem that the individual pulses are smeared in time. This problem is linked to resonances of the individual transducers. With the 15 correlated excitation of the plate in the first aspect, each actuator imparts an impulse directly to the integration medium of the plate. These transducers may be made very small, with associated self-resonances far above the sampling frequency. The digital impulses are then 20 clean and suffer less from time-smearing complications.

The principle of integration of digital pulses relies on a linear integration medium, which in this case is formed by the 2D plate. The individual pulse transducers are not required to be linear actuators, since the pulse 25 from each non-linear transducer is summed in the linear plate.

This therefore represents a scheme by which a non-linear transducer/actuator may be employed for audio



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reproduction without the need for pre-processing to correct for its transfer function. This opens up many possibilities for new transducer mechanisms, for example magnetostrictive materials and nematic liquid crystals.

5 One possibility for the non-linear transducers is a uni-polar device, for example using a nematic liquid crystal actuator. In this case it is relatively easy for an applied electric field to polarise the liquid crystal molecules and align them in the direction of the electric
10 field. However, the time constant for the molecules to return to their rest position after the electric field is removed can be very long. This actuator is therefore efficient in producing a digital pulse of one polarity only, which makes the reproduction of bipolar audio signals
15 very complex. A scheme by which an audio signal may be produced would require the delicate cancelling of stimuli on opposite phases of a particular mode. The inevitable mismatch in these stimuli would degrade the quality of low level signals, making this solution a poor one.

20 However, uni-polar devices may be employed in a bi-layer scheme. In this case one transducer layer above the symmetry line of the plate produces one polarity of force impulse, whereas an identical plane below this line produces the other polarity. In this manner, both positive
25 and negative impulses may be produced with uni-polar actuators, which opens up the option of devices such as nematic liquid crystal actuators.

Active layers of transducer material applied to a plate

together with a printed electrode represent a simple and cheap method of manufacture. Furthermore, for the case of a transparent transducer layer, such as a nematic liquid crystal, the electrode may also be patterned out of a conducting transparent film, such as indium tin oxide, forming a truly transparent loudspeaker.

The use of stimuli applied to closely spaced exciters on a bending wave plate may give rise to good correlation between exciters and a workable digital loudspeaker. The quality of digital integration in this scheme may be greatly superior to existing concepts centred on 3D acoustic integration of the digital signal. Furthermore, this scheme may exhibit the following benefits over analogue; increased efficiency, control over directivity and diffusivity, linearisation of highly non-linear devices, ability to use uni-polar devices. As compared with alternative digital concepts, the invention may allow use in the near field, minimisation of time smearing of the digital pulse and/or ease of manufacture.

In an alternative aspect the invention provides an array with a large transducer spacing, not small. This aspect of the invention covers the situation where a set of digital pulses is applied to a plate, where the spatial separation of the pulses is relatively large. The consequence of the large separation is a break in the correlation between the motion of the plate at each transducer position. Consequently, the motion resulting from each transducer may be thought of as independent,



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provided the separation of the transducers is large compared to the bending wavelength at the frequency of interest.

The situation described above allows a very simple implementation of a digital loudspeaker. Here, an array of transducers produces square wave mechanical stimuli to a plate. These stimuli produce audio pulses, with little interference between neighbouring transducers due to the break in spatial correlation between these points. The audio pulses integrate in the air to give an approximation to the analogue audio signal to be reproduced.

It is important to note that the panel in the second aspect is not performing the digital integration, and is in fact doing almost the opposite. The stimuli must be correlated in time in the integrating medium in order to sum to give the required waveform, whereas in the plate the transducers are purposely placed at positions with a low relative correlation. In the 3D acoustic space surrounding the plate, provided the separation of the transducers is less than the wavelength in air at the frequency of interest, there is a large correlation between the responses to each transducer. The air therefore provides the integrating medium, where the motion in the plate resulting from each transducer sums up to give an approximation to the target waveform.

This second aspect describes a digital loudspeaker that may be greatly simplified in construction over one comprised of a set of truly independent, individually

addressable transducers.

The requirement for decorrelation between the transducer positions imposes constraints on the transducer density, for a given panel and bandwidth. In particular
5 the spacing must be large compared to the bending wavelength at the low frequency bandwidth limit. This in turn limits either the number of transducers for a given bandwidth, or the bandwidth achievable for a given number of transducers.

10 The limits on the bit resolution (determined by the number of transducers) and bandwidth may limit the resolution of the output.

The use of a resonant plate implies a degree of time smearing of each digital pulse. This in turn implies a
15 non-perfect integration of the pulses to give the analogue audio signal, which may be manifest as a distortion.

The digital integration occurs in a similar manner to an array of individual loudspeakers i.e. it occurs in the 3D acoustic space surrounding the 2D array.

20 Digital integration according to the second aspect is designed to operate at a significant distance from the transducer array. Therefore, this approach may not be applicable to near field listening, such as telephony.

For either aspect Piezo transducers may be used to
25 actuate the panel, which have a number of advantages. These include a very high efficiency, low cost, and ease of manufacture.

A good resolution of transducers on the plate is easily



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achievable with piezo films and printed conductive inks.

A specific embodiment of the invention will now be described, purely by way of example, with reference to the accompanying drawing which shows a loudspeaker for use in 5 the invention.

The drawing shows a beam (1) much longer than it is wide which provides a plurality of resonant bending wave modes along the length of the beam. If the beam is narrow compared with its length, the bending across the beam will 10 not be important, especially at lower frequencies. Accordingly, the specific example described represents a quasi-one-dimensional implementation of the invention. This makes driving the resonant bending wave modes much simpler.

15 The transducer is intended to operate in a predetermined range, for example 200 Hz to 10kHz.

A plurality of transducers (3) are provided along one side of the beam. The transducers have a spacing of order 1cm or less, so that their spacing is less than the bending 20 wavelength at the high frequency limit, in the present example at about 10kHz.

Bending waves are dispersive, i.e. the wave speed is a function of frequency. Accordingly, the transducers may be pulled in sequence from left to right along the beam, at a 25 speed characteristic of a bending wave at a particular frequency. That bending wave will accordingly be preferentially excited, and will produce an acoustic output at that frequency, perhaps after reflecting off boundaries



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and interfering to produce a resonant bending wave mode.

A digital signal processor (5) having a signal input (7) is shown, connected to the transducers by a data bus (9). In order to adjust the volume of the emitted sound, a variable number of transducers are excited. For a low volume, digital pulses are applied to a small number of transducers along the length of the beam whereas for a higher volume a larger number of pulses is applied to the beam.

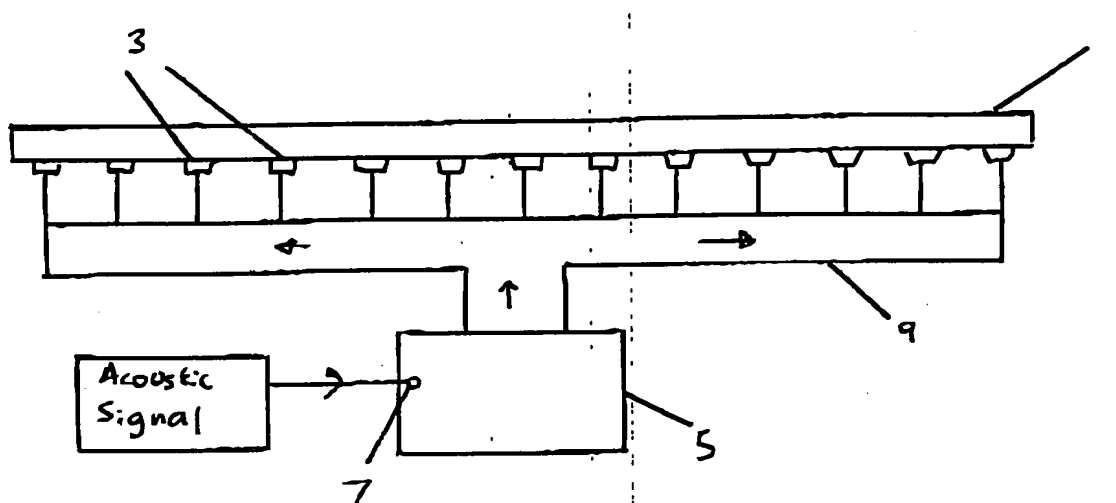
10 It is not intended only to excite resonant bending wave modes at one particular frequency. The acoustic signal provided at input (7) will have a frequency characteristic corresponding to a number of frequencies and corresponding amplitudes. If the input signal is a conventional signal, 15 the frequency information can be obtained by a Fast Fourier Transform, or otherwise, that is well known. The correct volume for each individual frequency component can be excited simultaneously to build up an acoustic output, corresponding to the acoustic signal input.

20 The invention is not limited to a quasi-one-dimensional beam in which the only important resonant bending wave modes are those along the length of the beam. The invention can also be applied to a plate with a plurality of transducers arranged in a two dimensional array over the 25 plate. With a knowledge of resonant bending wave modes and the phase differences between each mode the transducers can be driven to preferentially excite modes at predetermined frequencies.

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